REPORT DOCUMENTATION PAGE

Form Approved
OMB NO. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE ~~October 1997~~	3. REPORT TYPE AND DATES COVERED Final Jun 94 - 31 May 97

4. TITLE AND SUBTITLE	5. FUNDING NUMBERS
Vibration, Stability, and Transient Response of Helicopters with Elastically Tailored Composite Rotor Blades	DAAH04-94-G-0206

6. AUTHOR(S)

Edward C. Smith

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(ES) The Pennsylvania State University University Park, PA 16802	8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Research Office P.O. Box 12211 Research Triangle Park, NC 27709-2211	10. SPONSORING / MONITORING AGENCY REPORT NUMBER ARO 32145.4-EG-YIP

11. SUPPLEMENTARY NOTES

The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution unlimited.	12 b. DISTRIBUTION CODE

19971203 041

13. ABSTRACT *(Maximum 200 words)*

Aeroelastically tailored composite rotor blades offer significant potential for improved stability, reduced vibration, simplified hub design, and improved handling qualities of rotorcraft. Development of new analytical tools to predict the complex dynamic behavior of these rotor systems is essential to the integration of tailored blade technology into next generation rotorcraft systems. The focus of the present work has been: (1) Advancements in analysis methods for open section composite beams, subject to warping restraint effects, (2) Advancement in cross-sectional modeling of thick-walled composite blade sections, (3) Development and application of an aeroelastic analysis for investigation of composite elastic tailoring for stall alleviation and vibration reduction.

DTIC QUALITY INSPECTED 3

14. SUBJECT TERMS			15. NUMBER IF PAGES
			16. PRICE CODE

17. SECURITY CLASSIFICATION OR REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

Vibration, Stability, and Transient Response of Helicopters with Elastically Tailored Composite Rotor Blades

FINAL PROGRESS REPORT

Edward C. Smith, Principal Investigator

September 29, 1997

APPROVED FOR PUBLIC RELEASE;

DISTRIBUTION UNLIMITED

PROBLEM STATEMENT

Aeroelastically tailored composite rotor blades offer significant potential for improved stability, reduced vibration, simplified hub design, and improved handling qualities of rotorcraft. Development of new analytical tools to predict the complex dynamic behavior of these rotor systems is essential to the integration of tailored blade technology into next generation rotorcraft systems. The focus of the present work has been: (1) Advancements in analysis methods for open section composite beams, subject to warping restraint effects, (2) Advancement in cross-sectional modeling of thick-walled composite blade sections, (3) Development and application of an aeroelastic analysis for investigation of composite elastic tailoring for stall alleviation and vibration reduction.

KEY ACCOMPLISHMENTS and RESULTS

New structural models for elastically tailored composite rotors have been developed and validated. For open-section composite beams (bearingless rotor flexbeams), new finite elements have been formulated to accurately capture out-of-plane warping restraint effect. This phenomenon can dominate the torsional response and control loads of bearingless rotors and current aeroelastic finite elements lack the ability to capture this effect. The new beam element includes both elastic twist, ϕ_z, and elastic twist rate, ϕ'_z, as degrees of freedom. Classical kinematic boundary conditions for restrained torsional warping can be imposed using this modified beam element and excellent correlation with detailed shell element solutions has been demonstrated. It was shown that the new model could accurately predict torsion response for uncoupled and coupled cases. In addition, it is capable of predicting bending due to torque loading and torque due to bending loading in bending-torsion coupled beams. It was also shown that the new element could model arbitrary boundary conditions, taper, and a distributed spanwise loading with great accuracy. The new element contains only one more degree of freedom over a standard St. Venant torsion representation. Implementation of the new element is also straightforward. Therefore the goals of a computationally simple yet accurate torsion model have been met. An *AIAA SDM Conference Proceedings Paper* and an *AIAA Journal* paper have been published describing this aspect of the research in detail.

A refined composite beam theory for thick-walled composite blades has also been formulated and validated. This method builds on the Vlasov-type cross section approach and includes corrections for both nonuniform shear flow (associated with torsion of thick-walled beams) and finite transverse shear stresses acting through thdthickness of the blade spar (based on the Reddy theory for thick laminates). Results of the analysis were validated against detailed finite element solutions calculated using three-dimensional solid elements. An advantage of the refined theory is that it gives results of comparable accuracy to that of 3-D FEM in a fraction of the time. Results indicated that the shear flow correction played an important role in all torsion-related stiffness coefficients. The transverse shear within the laminate walls only contributed to transverse-shear related beam stiffness terms. Baseline Vlasov tends to breakdown for thickness ratios of approximately 15% due to shear strain effects. Transverse shear effects on bending stiffness can be noticed for ply angles in the 15- 45 deg range and for thickness ratios greater than 20%. In general, the shear strain correction has a larger effect (on the order of 20-30% error compared to baseline Vlasov-theory for thick-walled beams) than higher order transverse shear theory (on the order of 8-10% differences with baseline theory). Two *AIAA SDM Conference Proceedings Papers* have been published describing this aspect of the research in detail.

The refined composite beam finite element model has also been implemented into a free vibration analysis for composite beams. The new analysis is computationally efficient and directly captures the spanwise warping restraint effect by including appropriate beam torsion degrees of freedom. This element was validated against previously published experimental data and detailed finite element solutions for rotating composite I-beams with various elastic couplings.

Formulation of a composite blade aeroelastic analyses, including blade stall models and the new torsional finite element, was also completed. This analysis uses the new torsion finite element model described above for open section flexures and the new thick-walled, multi-cell Vlasov analysis for cross-section properties of the blade sections. A coupled trim procedure is implemented to capture changes in steady hub loads due to elastic deformations and separated flow on the blade. Related results addressing aeroelastic tailoring potential for stall alleviation and vibration reduction are forthcoming in Spring 1998.

LIST of MANUSCRIPTS

Floros, M. and E.C. Smith, "Finite Element Modeling of Open-Section Composite Beams with Warping Restraint Effects," *AIAA Journal, Vol.* 35, No. 8, August 1997, pp. 1341-1347.

Floros, M. and E.C. Smith, "Finite Element Modeling for Open Section Composite Beams with Warping Restraint Effects," *Proceedings of the 37th AIAA/ASME/ ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference*, Salt Lake City, April 1996.

Centolanza, L., E.C. Smith, and B. Kumar, "Refined Structural Modeling and Structural Dynamics of Elastically Tailored Composite Rotor Blades," *Proceedings of the 37th AIAA/ASME/ ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference*, Salt Lake City, April 1996.

Floros, M., "Finite Element Modeling for Open Section Composite Beams with Warping Restraint Effects," *M.S. Thesis, Aerospace Engineering Department,* The Pennsylvania State University, August 1996.

Centolanza, L. and E.C. Smith, "Refined Structural Modelling of Thick-Walled Composite Beams," accepted for publication in *Proceedings of the 38th AIAA/ASME/ASCE/ AHS/ ASC Structures, Structural Dynamics, and Materials Conference*, Long Beach, April, 1998.

SCIENTIFIC PERSONNEL

Edward C. Smith, Assistant Professor of Aerospace Engineering
AHS National Membership Award, May 1996
AHS National Membership Award, May 1995
Best Paper Presentation Award - AHS Forum Dynamics Sessions, May 1995

Matthew W. Floros, Graduate Research Assistant, Aerospace Engineering
AHS Vertical Flight Foundation Scholarship, May 1996, earned M.S. in
Aerospace Engineering, August 1996.

Louis Centolanza, National Defense and Science Foundation Graduate Student Fellow,
Aerospace Engineering, AHS Vertical Flight Foundation Scholarship, May 1996,
earned M.S. in Aerospace Engineering, December 1997.

INVENTIONS - None filed

TECHNOLOGY TRANSFER

The primary technology transfer has been with Dr. Mark Nixon with the US Army at NASA Langley Research Center. Numerous technical discussions and progress briefings were conducted throughout the grant period. There has also been interaction with technical personnel at Advanced Technologies Incorporated (Mr. Peter Dixon) in Newport News, VA. Additional technical discussion related to future directions of this project was also conducted with Mr. Bob Hansford at Westland Helicopters and Dr. Joy Sen and Dr. Frederick Straub at McDonnell Douglas Helicopter Systems (now Boeing Mesa). Presentations on the composite blade modeling research were also delivered at the ARO Beamology Workshop and at the ARO Aeroelasticity Workshop.